Gamma-Ray Astronomy Programs Working Group

Updated Science Priorities:

February 1999

Introduction

This document provides a brief overview of the recent discussions of the Gamma-Ray Astronomy Programs Working Group (GRAPWG). The GRAPWG is an ad-hoc committee formed by NASA to provide recommendations about the future of gamma-ray astrophysics. More information on the GRAPWG can be found at http://universe.gsfc.nasa.gov/grapwg.html.

The GRAPWG is currently at work updating the full report, which was first published in 1997. The full update will be available in both printed and electronic form. Public comments on the content of this or any other GRAPWG document are most welcome.

GRAPWG Current Membership

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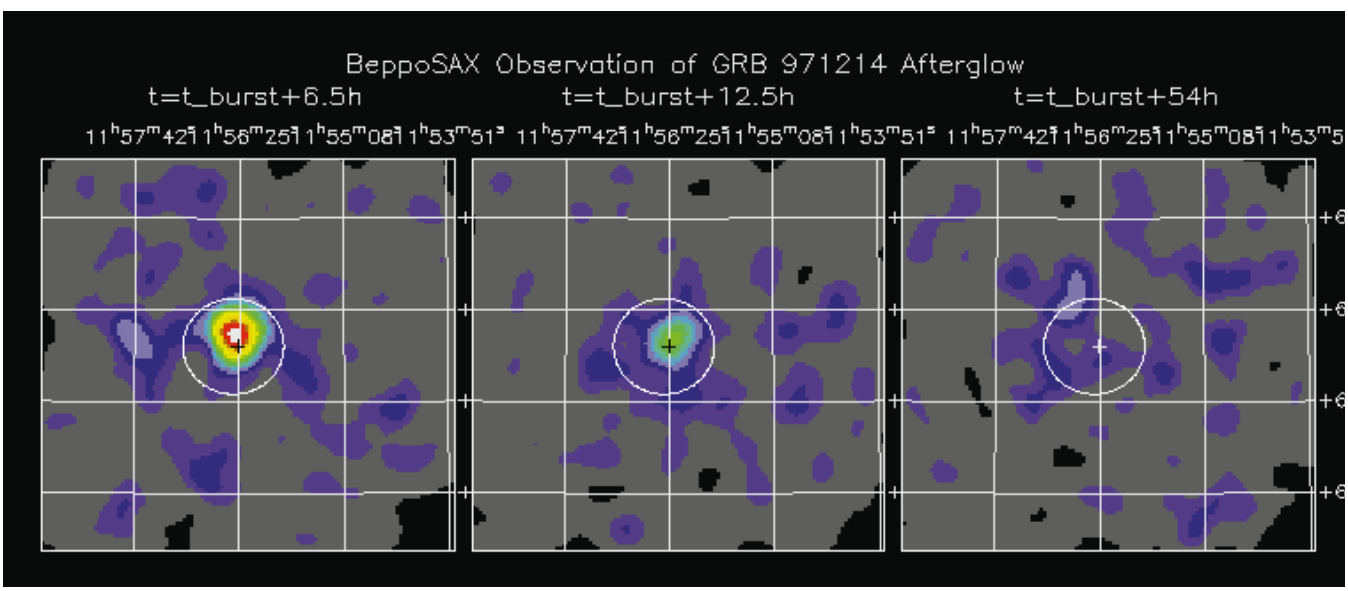
Science Highlights

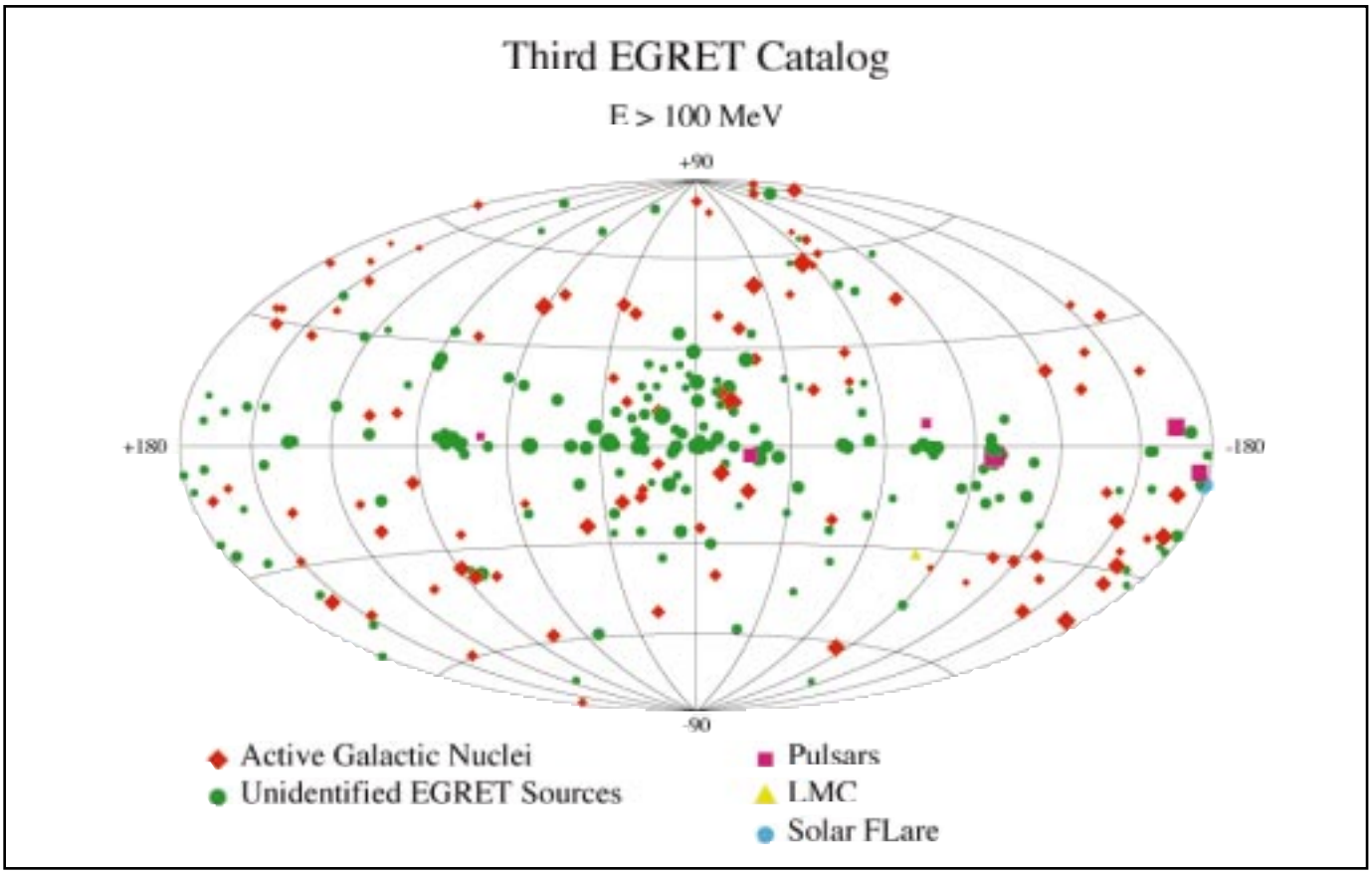
Since the last GRAPWG publication, gamma-ray astronomy has seen several exciting developments. From gamma-ray bursts to diffuse emission, the last two years have given astronomers much more information about the high-energy universe. A few of the key highlights are described below.

Gamma-ray bursts: No field of gamma-ray astronomy has changed as much in the last two years as gamma-ray burst studies. Thanks to rapid notifications of gamma-ray burst positions, the multi-wavelength study of GRBs has provided wonderful insights into the gamma-ray burst phenomenon. The study of X-ray and optical afterglows, largely enabled by the BeppoSAx mission, have allowed precise locations of several gamma-ray bursts. The measurement of distances for several burst sources has confirmed the extragalactic origin of GRBs. Provocative identification with galaxies and supernova remnants have also been forwarded.



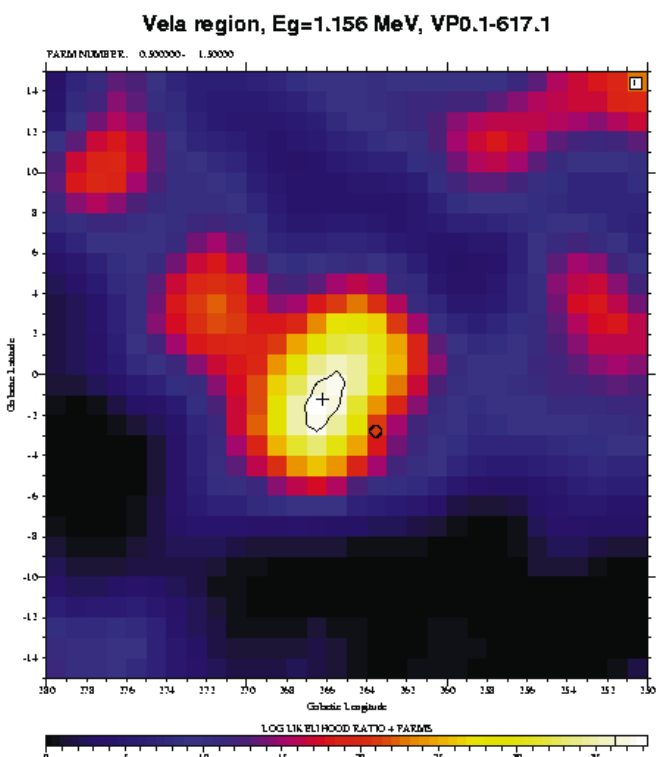
The study of burst afterglows at lower energies, such as this series of X-ray observations by BeppoSax, have revolutionized gamma-ray burst studies in the last two years.

3RD EGRET Catalog: As it nears the end of its most useful phase, the third CGRO/EGRET source catalog has shown an ever more crowded high-energy universe. A total of 270 sources of gamma-ray emission above 100 MeV are now know. The most prevalent known sources are the gamma-ray blazars and radio pulsars. The ever-growing class of unidentified sources continues to be of great interest.



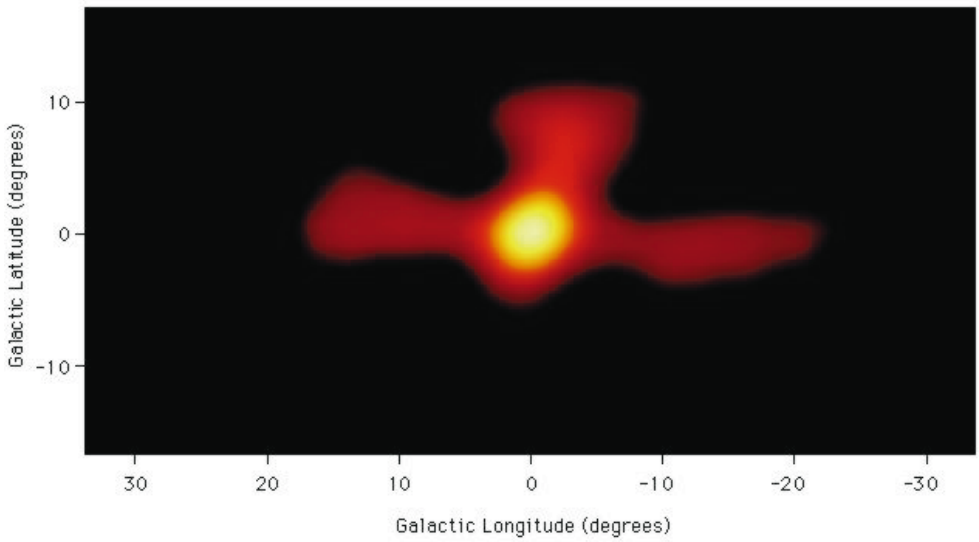
The sky distribution of the 271 sources in the third EGRET catalog. The most prevalent sources are 170 unidentifieds and 94 confirmed or likely active galaxies.

New COMPTEL Supernova Remnant: The gamma-ray detection of a previously unknown young supernova remnant in the Vela region in the light of 44Ti decay is an exciting new discovery. Along with X-ray observations, the 1.16 MeV emission has helped establish the age and distance to this remnant. Gamma-rays observations could be a very efficient way of finding such remnants.



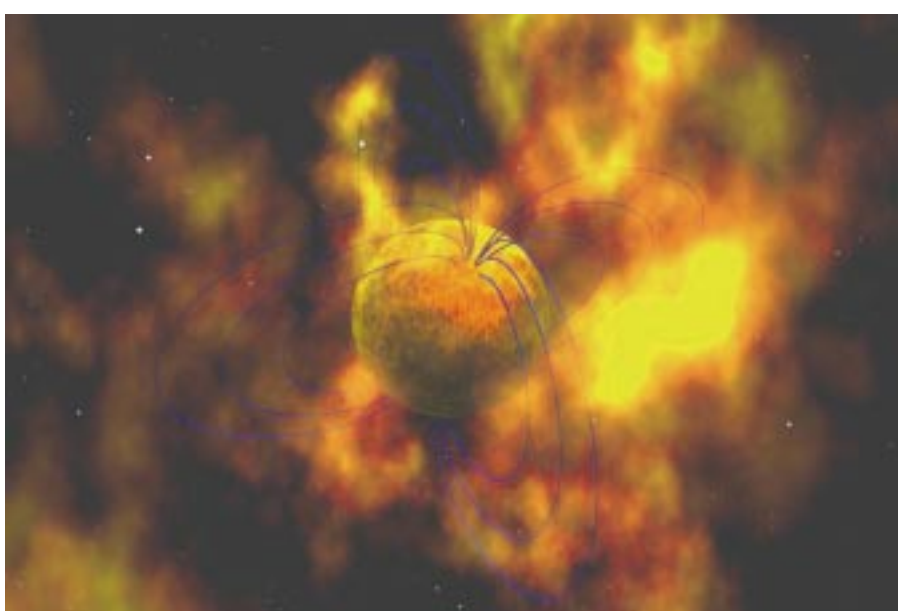
A likelihood map in the light of 44Ti showing the detection of the supernova remnant.

Detection of a Galactic Annihilation Fountain: The CGRO/OSSE instrument has been used to map the galactic plane in the light of 511 keV radiation from electron-positron annihilation. The sources and characteristics of this galactic diffuse emission has long been a source of controversy. Rather surprisingly, OSSE observations not only revealed the expected annihilation emission around the galactic center, but showed a cloud-like feature extending up from the galactic plane. The ultimate source of this annihilation fountain is the subject of intense speculation.



Map of the distribution of positrons towards the center of the Milky Way Galaxy, including the newly discovered antimatter "cloud". The brightest feature corresponds to the nucleus of the Galaxy. The horizontal structure lies along the plane of the Galaxy. The antimatter "cloud"is located above the Galactic center.

Soft Gamma-ray Repeaters as Magnetars: Clues to the origin of the soft gamma repeaters (SGR) have let to the picture of SGRs as magnetars - neutron stars with extremely high (>1014 Gauss) magnetic fields. In particular, hard X-ray observations of SGR 1900+14 and its corresponding spin rate and spin derivative confirmed the magnetar nature of this source.

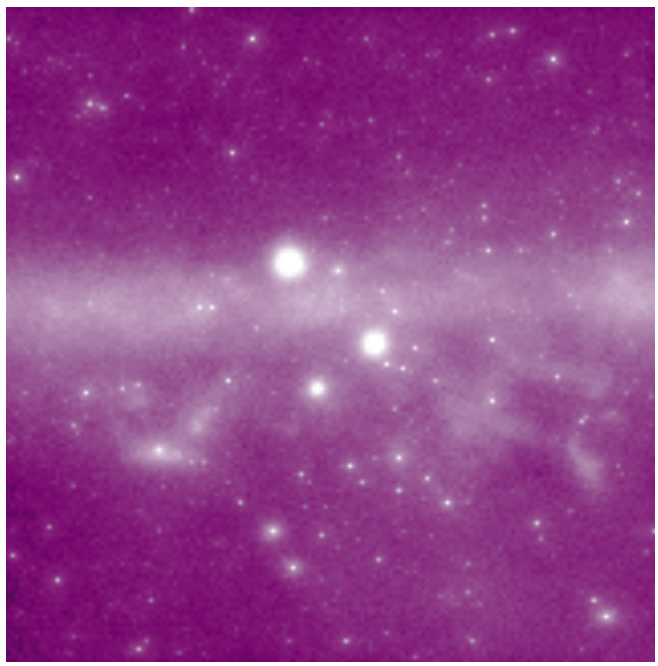


An artists rendition of a magnetar. There could be a very large population of magnetars in the Milky Way.

Mission Status

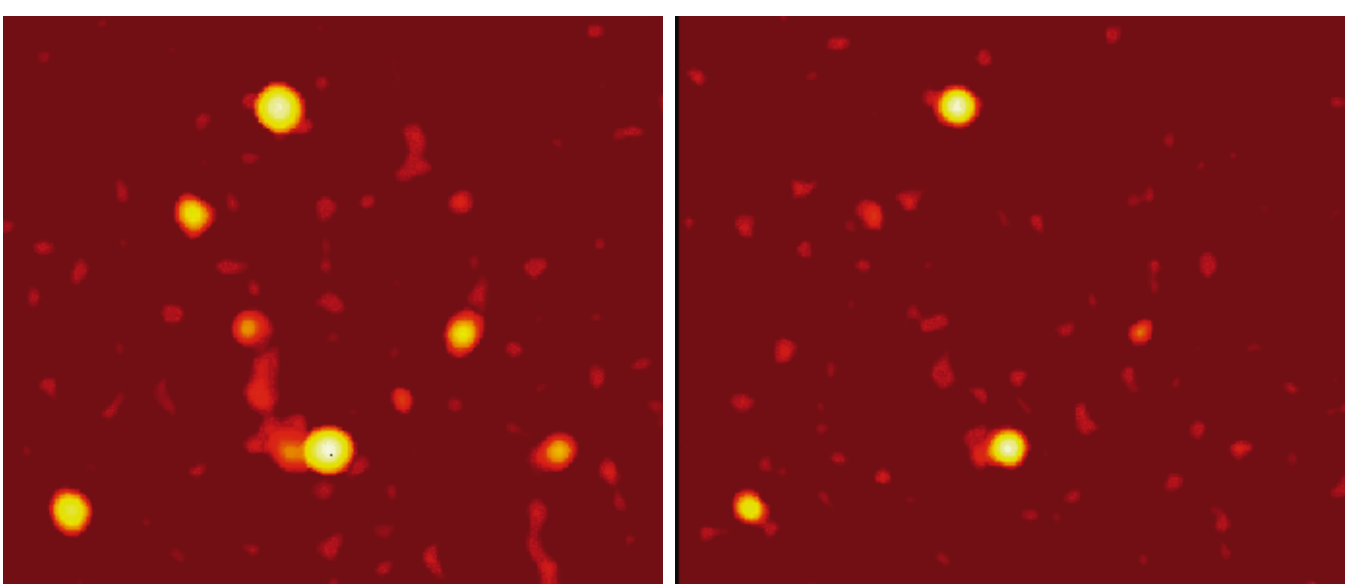
Several gamma-ray missions are in various stages of planning and preparation. The status of a few of the most relevant ones are given here.

GLAST: The Gamma-Ray Large Area Space Telescope (GLAST) is the next generation high-energy mission which will follow-on the great success of the CGRO/EGRET instrument. GLAST will detect gamma-ray emission from 20 MeV - 100 GeV with a ~3 steradian field of view. GLAST will provide more than an order of magnitude improvement in sensitivity over EGRET and give scientists a remarkable new view on pulsars, active galaxies, diffuse emission, gamma-ray bursts, unidentified sources, and maybe reveal a few surprises as well. GLAST is currently in NASA's strategic plan with a launch in 2005 expected. The GLAST instrument will be chosen in an open competition this year.



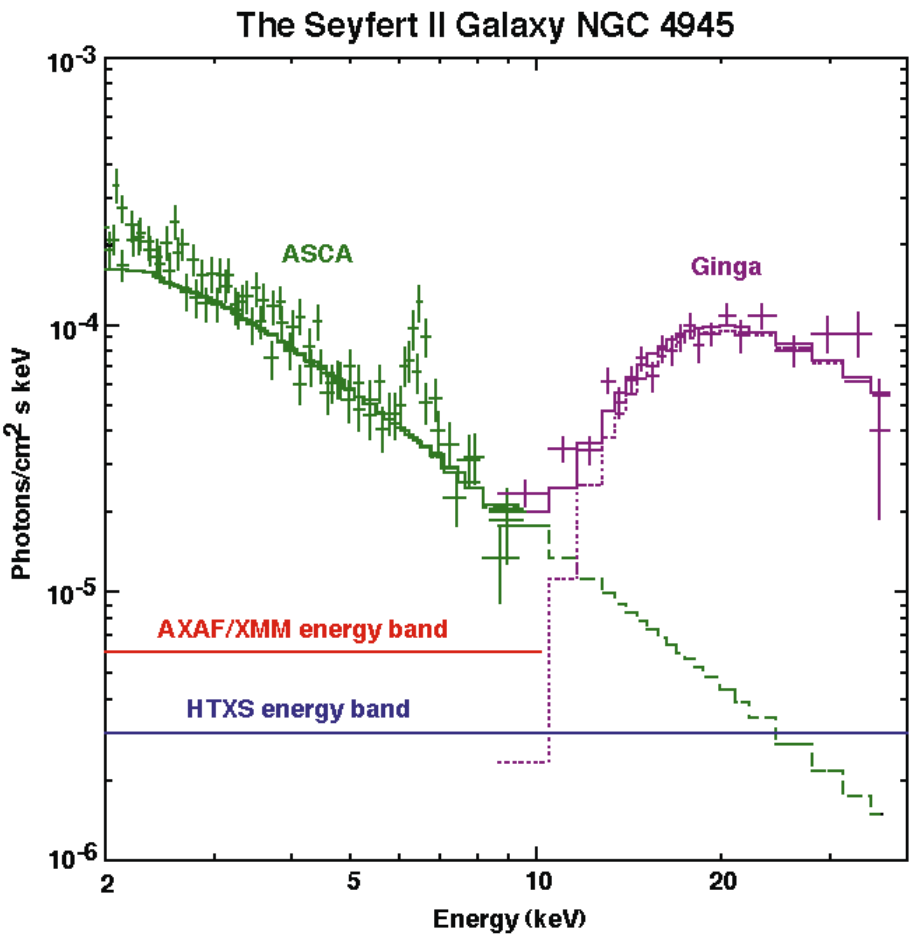
This simulated image of the galactic anticenter shows the gamma-ray sky as it will be seen by GLAST.

INTEGRAL: The European Space Agencies INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL) is planned for launch in 2001. INTEGRAL will provide spectral and imaging capabilities over the energy range from 20 keV to 10 MeV. Nucleosynthesis, Active Galaxies, and galactic compact objects are a few of the key astrophysical objects which will be studied with INTEGRAL.



Observations like these by the SIGMA/GRANAT instrument showing the variability of hard X-ray sources in the galactic center region are an important aspect of the proposed INTEGRAL science.

Constellation-X HXT: Current plans for the Constellation-X spacecraft call for a focusing hard X-ray telescope (HXT). This is a valuable component of this mission since previous X-ray measurements have shown that it is necessary to go beyond the 10 keV cutoff typical of most X-ray missions to fully characterize the broad-band spectra of many types of X-ray sources.



The spectrum of NGC 4945 shows the hard X-ray emission which is otherwise obscured. The ability to focus X-rays from 10 to 40 keV will provide a fundamental new look at the high-energy sky.

Draft Recommendations

What follows are the recommendations of the GRAPWG as agreed to during meetings in November 1998 and January 1999. They were derived from a wide-ranging discussion of promising areas of scientific investigation and technological advancement.

Top Priority Science Topics

The GRAPWG finds the following PRIORITIZED list to be the most compelling science topics that future hard x-ray and gamma-ray missions can address. The list is for the era beyond GLAST, Constellation-X HXT and an assumed gamma-ray burst Explorer mission. These are areas in which hard x-ray and gamma-ray astronomy offers unique capabilities for advancing our understanding of the universe. Each science topic is followed by a list of areas in which key contributions are expected.

The HIGHEST PRIORITY science topic identified by the GRAPWG is:

1) Nuclear Astrophysics: Sites of Gamma Ray Line Emission
- Abundance yields of explosive nucleosynthesis
- Mass cut between SN ejecta and core
- Supernova explosion physics
- Supernova explosion dynamics
- Supernova variety
- Nova explosion mechanism
- Sites of nucleosynthesis in the Galaxy and Universe
- Supernova rate in the Galaxy
- Better understanding of SN Ia cosmological distance scale calibration
- Cosmic ray interactions with interstellar gas
- Positron diagnostics of compact objects

Other high priority topics are:

2) Gamma Ray Bursts
- Links to star formation in the Universe
- Evolution and population of the most massive stars
- Possible sites of black hole formation
- New GRB populations - weak & short bursts missed by current missions
- Explosion physics
- Afterglow physics
- Probe of dusty matter in distant galaxies
- Probe of the intergalactic medium out to high redshift

3) Hard X-ray Emission from Accreting Black Holes and Neutron Stars
- First population study of absorbed Seyfert 2's
- Constraints on blazar spectra and diffuse IR background
- Non-thermal components in galactic transients
- Jets associated with galactic BHs and AGN
- Black hole parameters (spin, mass)
- Accretion physics

4) Medium Energy (300 keV - 30 MeV) Emissions
- Search for MeV blazars and spectral studies to understand emission
- Pulsar physics through broad-band spectral studies
- Components of diffuse galactic emission
- Extragalactic diffuse emission in poorly measured MeV band
- Non-thermal components from accretion-driven sources
- Cosmic ray interactions with the ISM (gamma-ray lines and continuum)

Top Priority Mission Recommendations

PREVIOUSLY RECOMMENDED MISSIONS

The GRAPWG finds that the scientific case for our previous top-priority missions has grown even stronger since 1997. These missions are:

GLAST
Constellation-X Hard X-ray Telescope
Gamma ray burst Explorer mission

Currently, GLAST and Constellation-X HXT are in the OSS Strategic Plan for new starts in 2002 and 2005, respectively, and the Swift gamma-ray burst MIDEX mission is in Phase A study. We continue to give our STRONGEST ENDORSEMENT to these missions, which are the backbone of NASA's future program in hard x-ray and gamma-ray astronomy.

FUTURE MISSIONS

For missions beyond the above three, the GRAPWG finds three mission concepts and one mission area to be the most exciting for addressing our top-priority science topics. These are (not in priority order):

MeV line and continuum Compton telescope mission
A factor of 30 step in sensitivity compared to CGRO and INTEGRAL will allow detailed studies of sites of nucleosynthesis in the universe and a deep survey of continuum sources. This mission would employ a new-generation of Compton telescope to operate in the 300 keV - 30 MeV region and address science items (1), (2) and (4). The feasibility of large imaging detector arrays based either on semiconductor or high density rare gases is being studied to enable a new mission in this challenging energy band.

Focusing optics hard x-ray telescope mission
A factor of 100 step in sensitivity compared to RXTE will answer key questions on the nature of accretion onto neutron stars and black holes and will allow detailed studies of sites of nucleosynthesis in the universe. New multilayer mirror technology would enable the mission to operate in the 10 - 200 keV range and address science items (1) and (3).

Hard x-ray survey mission
A factor of 100 step in sensitivity compared to the only previous all-sky hard x-ray survey (HEAO-1) will allow discovery of the predicted, but so-far unobserved, class of absorbed Seyfert 2's that are thought to make up half of the total inventory of AGNs. A large area array of new-technolo-

gy solid state detectors, used in conjunction with a wide field-of-view coded aperture, would cover the 10 - 500 keV region and address science item (3). The International Space Station is a possible platform for such an instrument.

Gamma-ray burst mission

Gamma-ray bursts are one of the most exciting and scientifically important phenomena in astrophysics. Future missions beyond HETE-II and a gamma-ray burst Explorer will be required to fully understand and exploit them. The GRAPWG finds that the decision on what wavelength band and instrumental capabilities are optimum for future progress must await results from upcoming missions.

OTHER RECOMMENDATIONS

Gamma-ray Astrophysics is a broad enterprise covering many other efforts including technology development, data analysis, and theory. The GRAPWG is recommending that the following items receive special consideration:

TeV Astronomy: Aside from their independent successes, ground-based gamma-ray observatories will provide an important complement to the GLAST mission. The GRAPWG endorses the continued development of TeV telescopes with low energy thresholds.

Balloon Program: The ultra-long duration balloon (ULDB) program offers great potential for both instrument development and significant science in gamma-ray astronomy. The GRAPWG recommends strong support by NASA for ULDB's. Optical Telescope Support: Both gamma-ray burst and active galactic nuclei studies benefit from a multiwavelength approach. In particular, optical telescopes can provide important monitoring capabilities which are difficult to achieve at other wavelengths. The development of a network of optical telescopes capable of near continuous monitoring gamma-ray transients is supported by the GRAPWG.

Interplanetary Network: Recent developments in GRB studies have underscored the already understood importance of GRB source localization. The GRAPWG endorses the continued operation and development of the Interplanetary Network as an effective means for deriving arcminute GRB locations.

Technology Development: Many exciting new technologies and opportunities are arising in the space sciences. The GRAPWG is particularly interested in seeing the development of technologies like Laue lenses (Bragg Concentrators) as an important instrument technology. The GRAPWG is also interested in the exploration of gamma-ray astrophysics opportunities on the International Space Station.

Data Analysis and Theory: Making the most of the rich astrophysical database expected from future missions is an important concern of the GRAPWG. We feel that adequate support for data analysis and theory is a cost-effective way of maximimizing the return from current and future experiments.

RECOMMENDATIONS FOR GAMMA-RAY BURST ASTRONOMY

The GRAPWG is particularly intrigued by the gamma-ray burst problem and the promise that bursts offer for fundamental studies in astrophysics. In addition to a dedicated gamma-ray burst mission in the post-explorer time frame, we recognize that there are multifaceted implications that burst have on many future missions. Below are listed some topics and recommendations on gamma-ray burst astronomy

Gamma-ray burst positions: Recent breakthroughs were enabled by rapid dissemination of GRB locations. The GRB community is united in the need for hundreds of arcsec locations.

Recommendation:

- The Swift GRB MIDEX mission now in Phase A should have high priority for flight
- HETE-II should be flown on schedule
- Support should continue for BATSE
- Support should continue for the Gamma-Ray Burst Coordinate Network
- Support should continue for the Interplanetary Network

GRB'S With GLAST: Despite the sparse observations, the CGRO/EGRET instrument has shown that high-energy emission contains a significant fraction of burst energy. Further observations are crucial for understanding the central engine and blast-wave interaction.

Recommendation:

- GLAST should continue to have a high priority
- Within GLAST, GRBS should have a high priority
- The GRB monitor currently planned for GLAST will greatly enhance its GRB capabilities and should be supported

TeV Observations of GRBS: GRB emission may very well continue into the TeV energy range. Observations in this region will greatly constrain models

Recommendation:

- Synergism between space-borne GeV observations and ground-base TeV observations should be recognized and exploited.

Optical Observations of GRBS: Simultaneous observations of GRBs with robotic telescopes are critical for understanding the prompt multiwavelength spectrum. Observations with large telescopes after the burst are key to obtaining precise locations and distances.

Recommendation:

- Global network of small, dedicated GRB robotic telescopes should be developed
- Time on major ground-base and space-based observatories should continue to be provided for GRB follow-up observations